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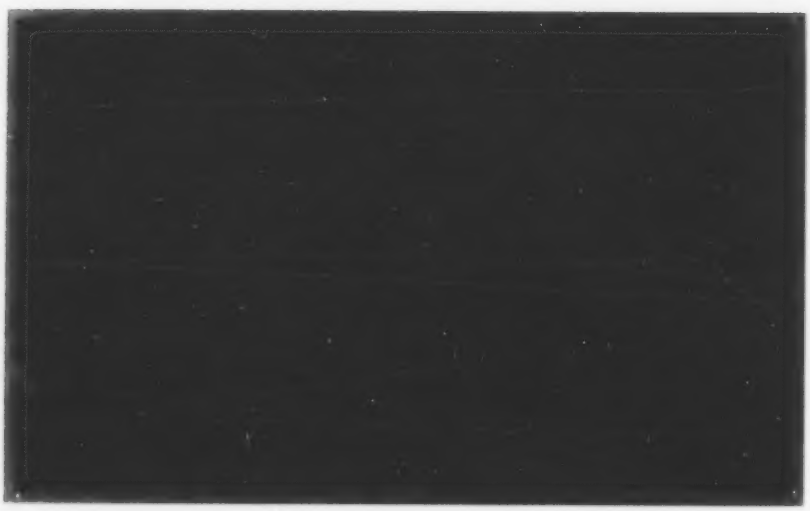

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CRT-857

Parallel Distributed Processing of Transportation/Land Use Systems: Theory and Modelling with Neural Networks

by

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Centre de recherche sur les transports — Publication #857

October 1992

Dépôt légal – Bibliothèque nationale du Québec,
Bibliothèque nationale du Canada, 1992

93-01800/

Parallel Distributed Processing of Transportation / Land Use Systems: Theory and Modelling with Neural Networks

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Abstract: A transportation / land use system is a complex spatial system composed of several elements representing the level of spatial accumulation. Elements are variables used to express the state of a system at a given point in time. Therefore the state of variables like interaction, accessibility, economic structure and population is the functional land use. It is suggested that sequencial urban modelling does not well represent complex urban dynamics. Instead, it is proposed a parallel distributed processing model composed of processors and links between processors with a specific internal parallel structure. Each processor is a set of neurons and weights between neurons forming a neural network. Parallel distributed processing offers new methodologies to represent the relational structure between elements of a transportation / land use system and thus the modelling of those systems.
Key words: Transportation, Land use, Modelling, Parallel Distributed Processing, Neural Networks.

Résumé: Un système transport / utilisation du sol est un système spatial complexe composé des plusieurs éléments représentant le niveau d'accumulation spatiale. Les éléments sont les variables utilisées pour exprimer l'état d'un système à un point donné dans le temps. Donc l'état de variables comme l'interaction, l'accessibilité, la structure économique et la population est représenté par l'utilisation fonctionelle du sol. Il est suggéré que la modélisation urbaine séquentielle ne représente pas de façon efficace une dynamique urbaine complexe. A l'instar, il est proposé une structure de modélisation distribuée en parallèle composé de processeurs et de liens entre les processeurs avec une structure parallèle interne spécifique. Chaque processeur est un ensemble de neurones et de poids entre les neurones formant un réseau neuronal. La computation distribuée en parallèle offre de nouvelles méthodologies pour représenter la structure relationnelle entre les éléments d'un système transport / utilisation du sol et donc la modélisation de ces systèmes.
Mots Clés: Transport, Utilisation du sol, Modélisation, Computation distribuée en parralèle, Réseaux Neuronaux.

1. Introduction

Land use can broadly be defined as a spatial accumulation of activities like production, transaction, administration and residence in a given space with highly dynamical relationships between those activities. More simply, urban land use is a reflection of the nature of urban activities in an area and of movements with other areas. There is however a limit to the accumulation of activities in an urban space that is apparent with the law of diminishing return, because when that limit is reached an area lose its comparative advantage. The tendencies and limits of decentralisation and sprawl of urban activities support this. It seems that until recently, decentralisation of activities and extension of the urban area was generally more economical than the production costs associated with a decentralized place mostly because transportation costs were low enough. The comparative advantages of a place varies over time and the transportation / land use system is in a permanent state of disequilibrium. A state of disequilibrium can be conceived has a continuing dynamic evolution of the system supported by the fact that it never tends to a precise and permanent state. The structural relationships between the elements (activities) of a system can change over time. Elements are variables used to express the state of a system and are based on what we reflects most the structure of the system. Traditionally, transportation / land use modelling has essentially foresaw to understand disequilibrium and to propose alternatives to resolve congestion problems and optimize the accessibility level. There were a lot of models but few geographical theories behind these models. According to Macmillan (1989), models can be prototypes for theories, applications of theories or representations of the reality. Therefore, modelling allows the theoretical representation of a transportation / land use system. However, no model is really efficient for synthesizing and forecasting the impacts of demographic and economic changes over such

[1] The author would like to thank Claude Comtois for useful comments.

a system. Most models are static, deterministic and required too much data to be applicable in a real context, or are limited over a specific sector such has housing (Berechman and Small, 1988). White (1989) maintains that writing a number of equations to describe the urban dynamic reveals nothing about the structural relations that these equations are modelling. In other words, equations that are appropriate for an historical period are not necessarily proper for another. Even equations developed for a specific urban system are often inapplicable to another urban system. A number of models adapt empirical urban theories to mathematics instead of adapting mathematics to urban processes and their dynamical relationships. This limits the potential of modelling as an useful tool for urban planning because using a model is a long process of implementation and calibration of its componentsy. Openshaw (1986,1989) shows that most models are based on theories that are rarely applicable in urban studies or planning. There exists a duality between theories and practices, but there is a tendency as the field come to maturity to integrate theoretical transportation / land use optimization concepts with operational planning practices (see Pryor, 1987). Regarding modelling, Berechman and Small (1988) demonstrate that dynamics, hazard, and agglomeration economies play a key role in the modelling of the urban structure. The hazard concept must be perceived has the set of urban processes that escape the planner's comprehension, control and forecast. Pumain, Sanders and Saint-Julien (1987) show that the urban structure and its evolution must not be considered has given, but has the result of complex interactions. It is precisely over these aspects that most of operational transportation / land use models are deficient. To overcome those deficiencies, Berechman and Small (1988) propose three alternatives: first, to add elements on agglomeration economies and dynamic adjustments over an existing model (such as the Lowry model); second, to add more realism and details to a dynamic model of agglomeration economies; third, to create a new model.

This article will attempt to create a new model in the field of transportation and land use (see Webster, Bly and Paulley, 1988). A new methodology in transportation geography will be developed, based on a model adaptable to any spatial entity. This claim seems presumptuous, but recent developments in Parallel Distributed Processing (PDP) has enabled geographers and planners with new tools and methodologies to simulate complex urban system dynamics (see Anderson and Rosenfeld, 1988 and White, 1989). To attain the objective of representing the transportation / land use system, a parallel model must be able to transform the structural relationships between its elements. We will first present the conceptual background of a transportation / land use parallel model. Second the mathematical framework of the model will be elaborated with a definition of the parallel structure and its dynamical adaptability. Third, a simulation of the model is performed. Last, a discussion on the relevance of parallel distributed processing for transportation / land use systems in general, and of the developed parallel model in particular is undertaken.

2. Mechanisms of a Transportation / Land Use Parallel Model

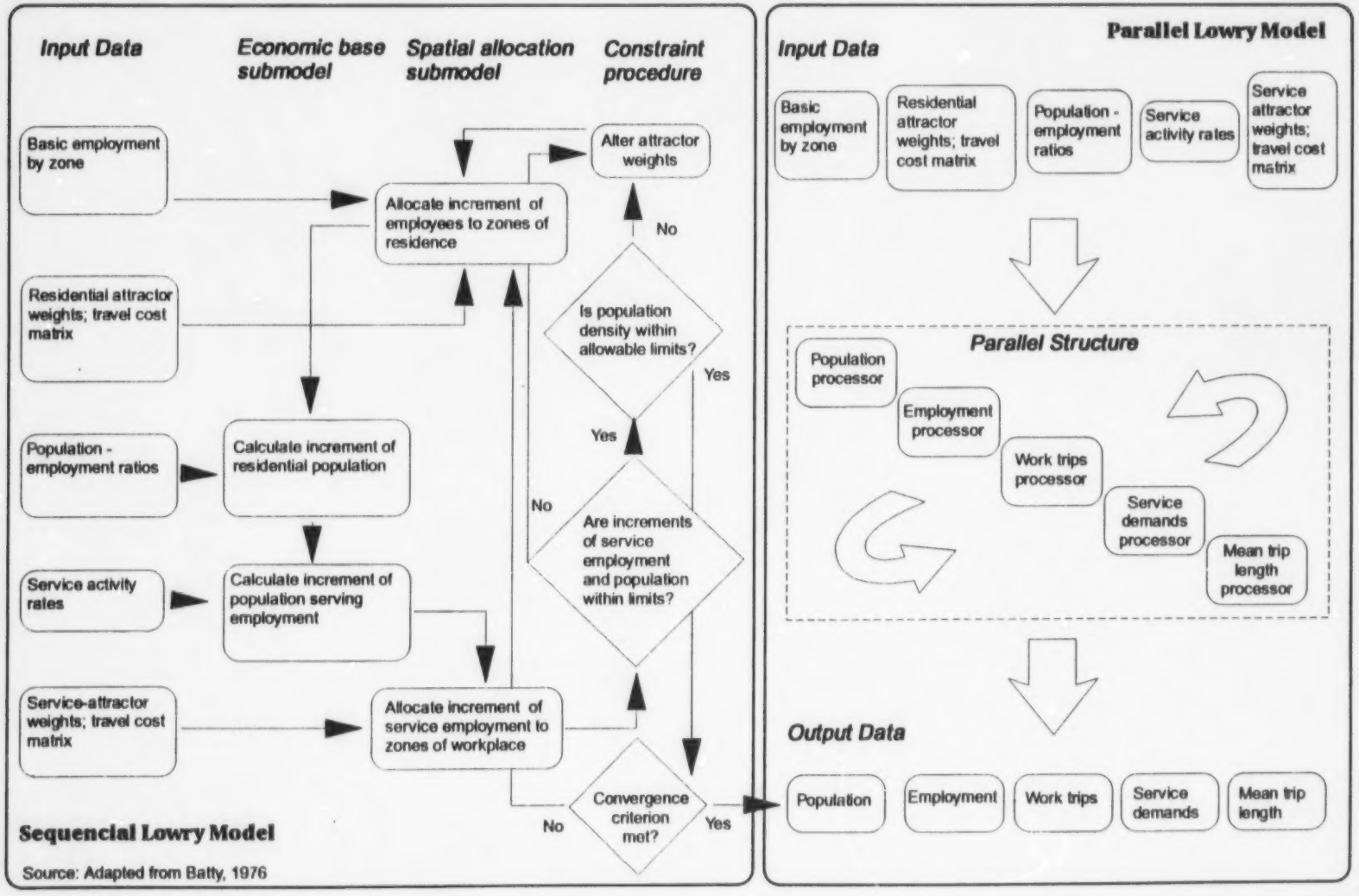
2.1 Concepts

We assume that a transportation / land use system is a parallel system. A parallel system involves that its elements are affecting each other simultaneously in time and space. Until recently, the modelling of spatial systems has strictly involved the development of sequential models that were trying to represents a parallel system in a straight forward logic with several steps. A classic example of this is the Lowry model (Lowry, 1964) where the employment per zone affected the population distribution which reaffected the employment. Iterations where performed until the results converged at some equilibrium point. Therefore iterations are a way to express a parallel system with sequential equations, but only one parameter of the model change for each step. A true parallel model is not foreseeable without a true parallel computing structure, but actual sequencial structures can simulate parallel behaviour. In fact, sequential and parallel models follow the same structure and logic because programs that represent them are sequential. Parallel processing involves the concept of granularity which is the relationship between the resources spend in coordination of the parallel system and the resources spent on its processing (Nolen, 1992). This concept applied to modelling entail that a part of the model affects the elements individualy and another part affects the relationships between the elements. Therefore, by drawing an analogy with parallel hardware structures, a parallel model PM is a set of processors p and a set of flows f between processors:

$$PM = \{p\ ,\ f\} \tag{1}$$

For each element of the model there is a processor. The processors process the equations related to the elements, while the flows are the outputs of processors towards other processors. Figure 2.1 presents a comparison between a sequential

Comparison between a Sequential and a Parallel Lowry Model **Figure 2.1**



and a parallel Lowry model. We do not mean that a Lowry like model is not relevant to transportation / land use planning, but that a parallel structure could efficiently represents a Lowry model. The sequential and the parallel Lowry model process and output the same variables. However, instead of having a straight forward structure to processes the information, a parallel model assume no specific order in the process structure. From a given set of inputs, each processor perform its set of equations until it require some information analyzed by another processor. It waits until that information is available and then proceed again. This is the same for all the processors. When all the processors have resolved their equations, they produce a set of outputs.

2.2 Mechanisms

By definition, the elaboration of a mechanism is a process of establishing the interrelationships between several concepts. In the proposed parallel model, the mechanisms are those related to land use changes. A change of one or several components will produce a change within all related components of the model if a minimal change that is defined as activation threshold is reached. This implies that a transportation / land use system that is not sufficiently affected, will not have significant changes in the volume and in the spatial distribution of its activities. The knowledge of the history of urbanization of a system is important to understand the actual state of that system and to make forecasts. Land use and transportation networks are the results of those historical processes of spatial accumulation. A transportation / land use system cannot remain stable for a long period of time because internal dynamical factors such as the aging of transportation infrastructures and changes in the demographic composition. In fact, we advance that there is no stability or equilibrium at all, because a transportation / land use system is continuously changing. Only the rate of change varies. This fact underlines that it is preferable to speak of a temporal state (the state at a specific point in time) instead of equilibrium in the case of spatial modelling. Change of the state of the transportation / land use system integrates itself in the context of external factors like the position of the city in the regional, national and international transportation system. Some of the most powerful external factors are the creation of economic blocs, the international division of labour and the internationalisation of exchanges that affect location of a great number of economic activities (see Scott and Storper, 1986). Consequently, it is important to evaluate the theoretical mechanisms that controls the land use changes through the elaboration of the logical linkages between elements and through the mathematical modelling of those linkages.

Most of modelling rests on the specification of the functional processes between the components of the developed model. To simplify the theoretical demonstration, we limit ourselves to four general basic components of a transportation / land use system. Those components are the accessibility, the interactions, the economic structure and the population. Accessibility is the general capacity (transportation supply) of a transportation system within an delimited area. Interactions are the movements of all modes between areas. The economic structure is the spatial accumulation in an area of economic activities like production and transaction. The population is the socio-economic attributes of the inhabitants of an area. Figure 2.2a proposes a parallel structure to conceptualize the theoretical mechanisms of land use changes. The parallel model is based on the principle that a transportation / land use system evolves from a state (time t) to another (time $t+1$) and so on (time $t+n$). Each state is the result of the previous state and of the changes occuring between the previous state and the actual state. Each processor representing a variable have an i index indicating a zone. This means that a processor can output spatially desegregated results.

The conceptual linkages between each elements composing the transportation / land use system are shown on figure 2.2b. In the chosen parallel structure, there are no links between the processors, except between each cycle. Therefore table 2.1 shows some basic theoretical assumptions of the relationship between each element implemeted as a processor in a parallel model.

Model Parallel Structure **Figure 2.2**

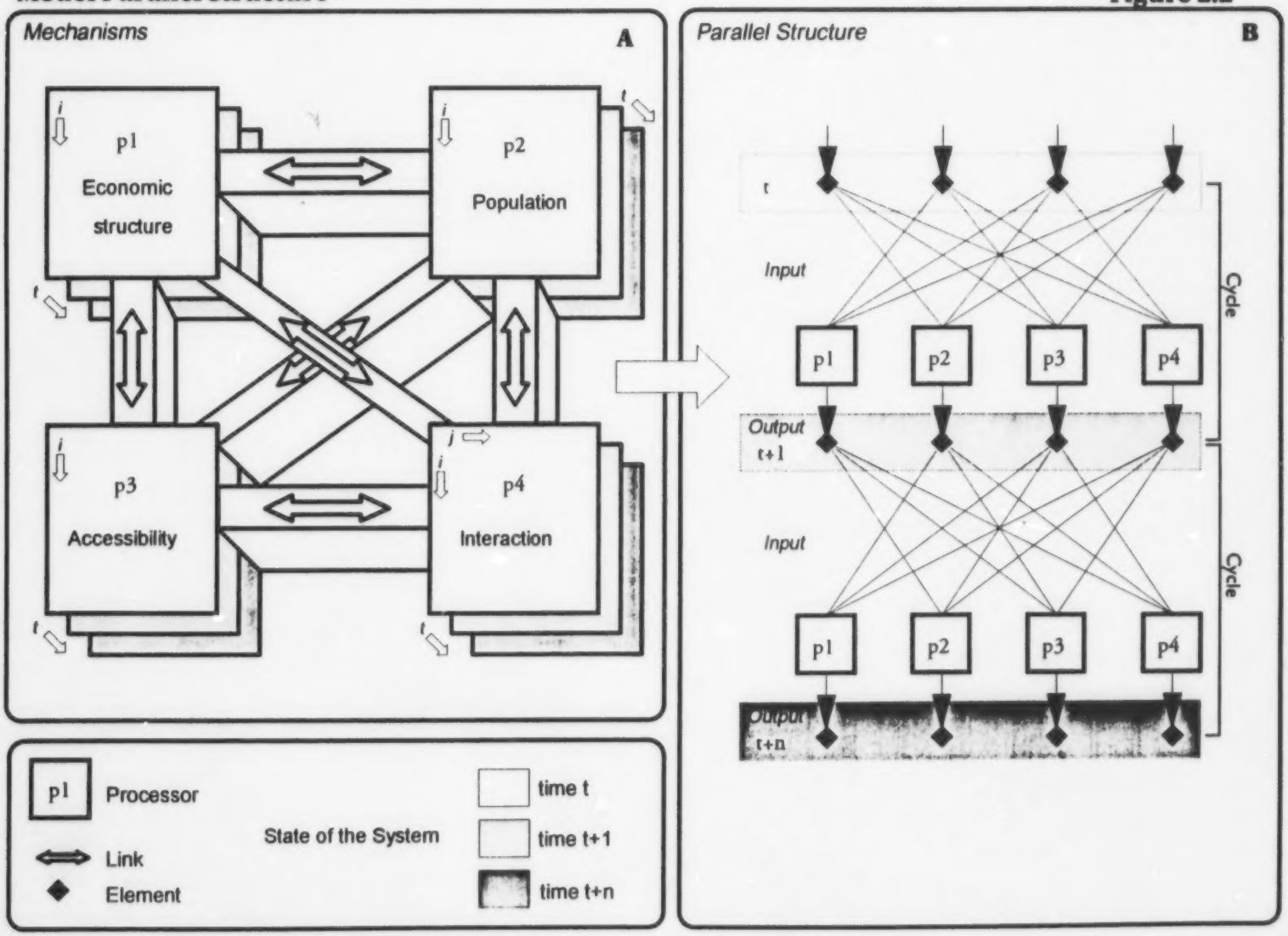


Table 2.1: Relationships between Elements of a Transportation / Land Use Parallel Model

	Interactions	Accessibility	Economic Structure
Accessibility	The more a zone offers a high transportation supply, the more movements between zones will be inclined to use this zone as an axis of movement towards other zones. Inversely, the intensity of interactions will determine the transportation network utilization level. An usage level higher than the capacity of transportation infrastructures creates congestions lowering the interaction level. There is a strong retroaction between supply and demand that influences the state of the system. Changes in accessibility has often an immediate impact over spatial interactions.	Accessibility influences itself only indirectly.	Accessibility influences economic structure only indirectly.
Economic Structure	The presence of an economic activity generates movements of persons, goods and information. The nature of urban activities is very diversified, hence a number of diversified interactions. A change in the economic structure influences the intensity of interactions that origins from that place. The spatial distribution, the volume and the nature of interactions influence the economic structure in two ways: first, interactions need transportation modes; second, the presence of interactions from one zone to another creates service activities.	The presence of transportation infrastructures gives an accessibility level that determines the nature of the economic structure. Accessible places generally have an important and diversified employment structure. The economic nature of a place will influence its complexity in transportation infrastructures and therefore its accessibility level by creating a demand. This underlines the relationships between the transportation supply given by accessibility and the transportation demand of economic activities.	The spatial accumulation of economic activities influence itself through the process of economies of agglomeration. Certain types of economic activities like services raise their efficiency if they are located nearby eachother. Investments in one sector of the economy generate employment in related sectors and particularly in the service sector.
Population	The population of a zone influences interactions of persons, goods and information. For home-based trip purposes, residential areas are important generators of spatial interactions. A change in the distribution and the volume of the urban population leads to changes in the nature, distribution and the volume of interactions, particularly those related to passenger movements.	The accessibility level influences the location of population because population, more specifically labour, look for a transportation supply to different urban zones. Certain modal and intermodal accessibility such as port accessibility is less important in the location of population. This kind of accessibility influences the location of population through its importance to certain activities that generates employment. The presence of population is an incitative factor for the construction of public transit or any kind of transportation infrastructure related to movements of people.	The economic structure has a direct impact over the spatial distribution and the volume of population. The economic structure can be represented by the distribution of labour in economic activities. Changes in the economic structure affect labor supply and often the distribution of population. Inversely, the population of a zone influences the economic structure with the creation of a number of services. The labor supply of a population is a factor for the settlement of economic activities.

Table 2.2: Types of Relationships between Elements of a Transportation / Land Use Parallel Model

	Interactions	Accessibility	Economic structure	Population
Interactions	Indirect	Direct	Direct	Indirect
Accessibility	Direct	Indirect	Direct	Indirect
Economic structure	Direct	Indirect	Direct	Direct
Population	Direct	Indirect	Direct	Indirect

Table 2.2 resumes the types of relationships between the elements. A direct relationship means that an element has a causal link with another. An indirect relationship indicates that an element influence another through another element. For instance interactions can influence itself only through the accessibility level.

Functional land use represents the state of a transportation / land use system through its elements: the interaction (T_{St}), the accessibility (A_{St}), the economic structure (S_{St}) and the population (P_{St}). Therefore, functional land use for a transportation / land use system S at time t (expressed as L_{St}) can defined as the set of those elements:

$$L_{S_t} = \left\{T^k , A^k , S^k , P\right\}_{S_t} \tag{2}$$

If the elements and their linkages are applied to the functional land use, it can be understand has a parallel structure. The following section will model that structure.

3. Mathematical Logic of a Parallel Transportation / Land Use Model

The first conceptual element of the parallel model is related to the state of the transportation / land use system that has been identified has the functional land use. Lets take L_{S_t} to identify the state of the system S (in a parallel model *PM*) for the time t and $E_{S_t}^N$ the N elements representing the level of spatial accumulation of interactions, transportation infrastructures, economic activities and of population. Each element is also the state (output) of a processor p. The result is the following relationship:

$$L_{S_t} = \left\{E_{S_t}^N \mid N = X, Y, \ldots, n\right\} \tag{3}$$

which is a simplified version of equation 2. Because no variable related to an urban system is entirely reliable, particularly in countries where national data gathering is not well developed, it is important to underline that each element is composed of its value and its error field. The error field ($e_{S_t}^X$) is the numerical interval of the error (or error area) for an element E^X. With that notion, the elements (E^X,E^Y,...,E^n) of the system S and time t are defined as:

$$\begin{aligned} E_{S_t}^X &= \left\{E_{S_t}^X , e_{S_t}^X\right\} \\ E_{S_t}^Y &= \left\{E_{S_t}^Y , e_{S_t}^Y\right\} \\ &\cdots \\ E_{S_t}^n &= \left\{E_{S_t}^n , e_{S_t}^n\right\} \end{aligned} \tag{4}$$

Initially, e is the error related to the data. The notion of error field can be incorporated into a more complete logic: the fuzzy field (Negotia and Ralescu, 1987; Zadeth, 1965). A fuzzy field is a method to find the membership of an element to a set. In classical mathematics, an element belongs or does not belong to a set. If $x \in A$, then x has a membership value of 1 to set A. Inversely, if $x \notin A$, then the membership will be 0. In the fuzzy field theory, this dichotomy is replaced by a membership function. If $u(x)$ is the membership function of the element x to a set, then this function is delimited by $0 \leq u(x) \leq 1$. An element belongs more or less to a set depending on the value of the membership function. The membership value ($P(x)$) is expressed by:

$$P(x) = \left(u \mid u{:}x \rightarrow [0,1]\right) \tag{5}$$

where u is the membership field. We suggest that the notion of error field can be incorporated to the fuzzy field. As a result, $u = e$. The membership value of element E^X to its set can be formulated by:

$$P\left(E_{S_t}^X\right) = \left(e \mid e{:}E_{S_t}^X \rightarrow [0,1]\right) \tag{6}$$

where e is element E^X membership function to its own set. The membership function of element E^X is bounded by its error field. It is likely that the membership function ($e(E^X)$) will take the shape of a normal curve or another relatively similar distribution. The median of this distribution will be the highest probable value (maximal membership) of the element E^X to its own set. In other words, the larger the error field, the smaller the probability attach to an element. The error field also vary in time. The farther in the future a projection is made, the less accurate are the results of that projection:

$$e^{X}_{St+1} = e^{X}_{St} + \frac{\delta e^{X}_{S}}{\delta t}$$
$$\frac{\delta e^{X}_{S}}{\delta t} = f\{\Delta t\} \qquad (7)$$

A transportation / land use system has a maximal functional accumulation of elements (interaction, accessibility, economic structure and population) which is dictated by the density of land use and transportation infrastructures. In other words, there is a limit to spatial accumulation. Therefore, the elements E^X, E^Y to E^n for the system S at time t can be submitted to the following constraints:

$$\begin{aligned} E^{X}_{St} &\leq C^{X}_{St} \\ E^{Y}_{St} &\leq C^{Y}_{St} \\ &\cdots \\ E^{n}_{St} &\leq C^{n}_{St} \end{aligned} \qquad (8)$$

where:
C_{St}^{X} = maximal functional value for the element E^X.
C_{St}^{Y} = maximal functional value for the element E^Y.
C_{St}^{n} = maximal functional value for the element E^n.

Now that the elements of the transportation / land use system has been defined, the next step in the elaboration of the parallel model consist to mathematically translate the relationships of the elements on figure 2.2 and tables 2.1 and 2.2. This gives the following parallel model:

$$\begin{aligned} PM &= \{ S_{St} , P_{St} , A_{St} , T_{St} \} \\ S_{St} &= f\left\{ \sum_{\forall i} P_{it} , \sum_{\forall i} A_{it} , \sum_{\forall i} T_{it} \right\} \\ P_{St} &= f\left\{ \sum_{\forall i} S_{it} , \sum_{\forall i} A_{it} , \sum_{\forall i} T_{it} \right\} \\ A_{St} &= f\left\{ \sum_{\forall i} P_{it} , \sum_{\forall i} S_{it} , \sum_{\forall i} T_{it} \right\} \\ T_{St} &= f\left\{ \sum_{\forall i} P_{it} , \sum_{\forall i} S_{it} , \sum_{\forall i} A_{it} \right\} \end{aligned} \qquad (9)$$

where:
T_{St} = interaction for the system at time t.
A_{St} = accessibility for the system at time t.
S_{St} = employment structure for the system at time t.
P_{St} = population for the system at time t.

$f[\ldots]$ represents the function that a processor must proceed to calculate the impacts on one element of changes in others. For time $t+1$, the parallel model PM simply becomes:

$$
\begin{aligned}
PM &= \left\{ S_{St+1} \, , \, P_{St+1} \, , \, A_{St+1} \, , \, T_{St+1} \right\} \\
S_{St+1} &= f\left\{ \sum_{\forall i} P_{it+1} \, , \, \sum_{\forall i} A_{it+1} \, , \, \sum_{\forall i} T_{it+1} \right\} \\
P_{St+1} &= f\left\{ \sum_{\forall i} S_{it+1} \, , \, \sum_{\forall i} A_{it+1} \, , \, \sum_{\forall i} T_{it+1} \right\} \\
A_{St+1} &= f\left\{ \sum_{\forall i} P_{it+1} \, , \, \sum_{\forall i} S_{it+1} \, , \, \sum_{\forall i} T_{it+1} \right\} \\
T_{St+1} &= f\left\{ \sum_{\forall i} P_{it+1} \, , \, \sum_{\forall i} S_{it+1} \, , \, \sum_{\forall i} A_{it+1} \right\}
\end{aligned}
\tag{10}
$$

and where:

$$
L_{St+1} = \left\{ T \, , \, A \, , \, S \, , \, P \right\}_{St+1} \tag{11}
$$

Therefore functional land use at time $t+1$ for the system S (L_{St+1}) is the set of the elements at time $t+1$. The main problem behind equations 9 and 10 is how to estimate $fl...l$? Since all transportation / land use systems have different levels of relationships between their elements, there is no unique equation that could be adapted to all systems. To find an induction structure that will represents the set of $fl...l$ in equations 9 and 10, we use a recent parallel modelling technique defined as the neural network.

4. Neural Network Modelling of a Parallel Transportation / Land Use System

Neural networks are mathematical models that simulate parallel information-handling features of biological systems made up of many simple elements called neurons (Korn, 1991). The representation of the information is based on the pattern of connections between neurons of the network (Caudill, 1990). Neural networks are organized as a set of layers sequentialy processing a set of inputs. One of the original aspects of neural networks is their capacity for induction. Given a set of examples, a neural network model will represent the relationships into an inference structure that can be used for deduction. The objective of neural network modelling of a parallel system is to find a configuration of weights for a processor that produce estimated results similar to the observed results. Therefore, a processor can be "trained" to answer properly to a set of inputs to produce another set of outputs. The elaboration of a neural network processor in a parallel model can be devided in three stages. First, the definition of the neural network. Second, the calibration by the configuration of the weights, and third the integration in the parallel model *PM*.

4.1 Definition of the Neural Network Processor

A processor that simulate the behaviour of a neural network is a neural network processor. Let a neural network processor be expressed by *net(p)*. For each processor *net(p)*, we use three layers, the input, intermediate and output. The intermediate layer is the internal processing structure of a neural network. The input layer X_p of processor p is defined by:

$$
X_p = \left\{ X_1, X_2, \ldots, X_{nX} \mid X_i = E_{Si}^X \right\} \tag{12}
$$

and the intermediate layer Y_p by:

$$
Y_p = \left\{ Y_1, Y_2, \ldots, Y_{nY} \mid Y_j = \sum_{\forall X_i} O_i^X W_{(i,j)}^{XY} \right\} \tag{13}
$$

and the output layer Z_p by:

$$Z_p = \left\{ Z_1, Z_2, \ldots, Z_{nZ} \mid Z_j = \sum_{\forall Y_i} O_i^Y W_{(i,j)}^{YZ} \right\} \tag{14}$$

where:
- X_i = Input neuron i.
- Y_i = Intermediate neuron i.
- Z_i = Output neuron i.
- nX = Number of input neurons.
- nY = Number of intermediate neurons.
- nZ = Number of output neurons.
- $W_{(i,j)}$ = Weight of the connection between neuron X_i of layer X and neuron Y_j of layer Y.
- O_i^X = Output transfer function of neuron i of layer X.

The output transfer function of neuron i of input layer X_p (O_j^M) is defined by:

$$O_i^X = O(I_i^X) = \frac{1}{1 + e^{-(X_i + \theta_i)}} \tag{15}$$

where θ_j is a bias. Equation 15 is applied again to layer Y_p to produce outputs on layer Z_p. Therefore, a set of inputs from layer X_p can be processed by the intermediate layer Y_p to produce an output layer Z_p.

4.2 Learning in a Neural Network Processor

Learning in a neural network is an iterative process where the weights ($W_{(i,j)}$, see equations 13 and 14) are ajusted until the calculated outputs of the neural network correspond to the observed results. To do so, the outputs of a processor p derived from equation 12, 13, 14 and 15 are compared with the desired results to see if the total error (E) is less than a fixed error margin (EM):

$$E_i = \frac{1}{2} \sum_i (D_i - Z_i)^2$$
$$E = \sum E_i \leq EM \tag{16}$$

where:
- D_i = the desired output for neuron i.
- O_i^c = the output of neuron i at output layer c calculated by the network.
- E_i = the error of neuron i.

To be consistent with the model, the error margin EM is equal to the error field e. If the total error is greater than the error margin, the weights between the layers are readjusted according to the following learning rule (Sejnowski and Rosenberg, 1986):

$$\Delta W_{ij}(t+1) = \beta (\delta_j^b O_i^a) + \alpha \Delta W_{ji}(t) \tag{17}$$

where:
- β = the learning constant.
- α = the momentum constant.
- δ_j^b = the error signal of neuron j of layer b.
- O_i^a = the output of neuron i of layer a.

We assume that layer a preceed layer b. The subscript t indexes the presentation number. For the output layer Z_p, δ_j^c is defined by:

$$\delta_i^Z = (D_i - Z_i)Z_i(1 - Z_i) \tag{18}$$

else, for the intermediate layer Y_j:

$$\delta_i^Y = Y_i(1 - Y_i)\sum_{\forall Z_i} \delta_j^Z W_{ij}^{ZY} \tag{19}$$

This procedure is repeated recursively until the output error E is less than a fixed error margin. Neural network trained with an error margin of 5% have a good capacity for generalization. This error margin often correspond to the accuracy of available data on a transportation / land use system.

4.3 Full Parallel Structure with Neural Networks Processors

With the methodology of neural network processors developed on the previous sections, the parallel model (equation 9) becomes:

$$\begin{aligned} PM = \{ & S_{St} , P_{St} , A_{St} , T_{St} \} \\ & S_{St} = net(S_{St}) \\ & P_{St} = net(P_{St}) \\ & A_{St} = net(A_{St}) \\ & T_{St} = net(T_{St}) \end{aligned} \tag{20}$$

where the state of the transportation / land use system (L_{St}) is still:

$$L_{St} = \{T , A , S , P\}_{St} \tag{21}$$

net(X) is a neural network processor related to element X. Figure 4.1 shows the structure of a parallel neural network and of a neural network processor. Each processor is able to estimate the impacts of the outputs of all other processor. The flows between processors are subject to a set of constraints (see equation 8). The parallel structure of figure 4.1b works as follows: first, we assume that all the neural network processors have been trained to produce a set of output with a given set of inputs. For instance, processor *p1* produces element E^1 at time $t+1$ from an input of elements E^2, E^3, and E^4 and time t. Second, all the elements are inputed to the processors to produce the results for time $t+1$. With the chosen parallel structure this is done simultaneously and no processor have to wait for information from others because there is no links between processors for a cycle (from time t to time $t+1$). The same process is repeated with the elements at time $t+1$ to have results at time $t+n$.

5. Simulation

In order to test the behaviour of the developed parallel model, a simulation of its dynamics was undertaken. Lets consider a fictive city characterized by four elements (variables) and ten zones (see table 5.1). The object is to find if a neural network processor is able to model linear and non-linear relationships between elements. There is no assumption that the fictive city is the reflection of the reality. Accessibility is an index of the overall capacity of the transportation system. Interactions are the total number of persons arriving in a zone in the morning peek hour. Employment is the number jobs in a zone. Population is the number of people living in a zone.

Parallel Neural Network Structure **Figure 4.1**

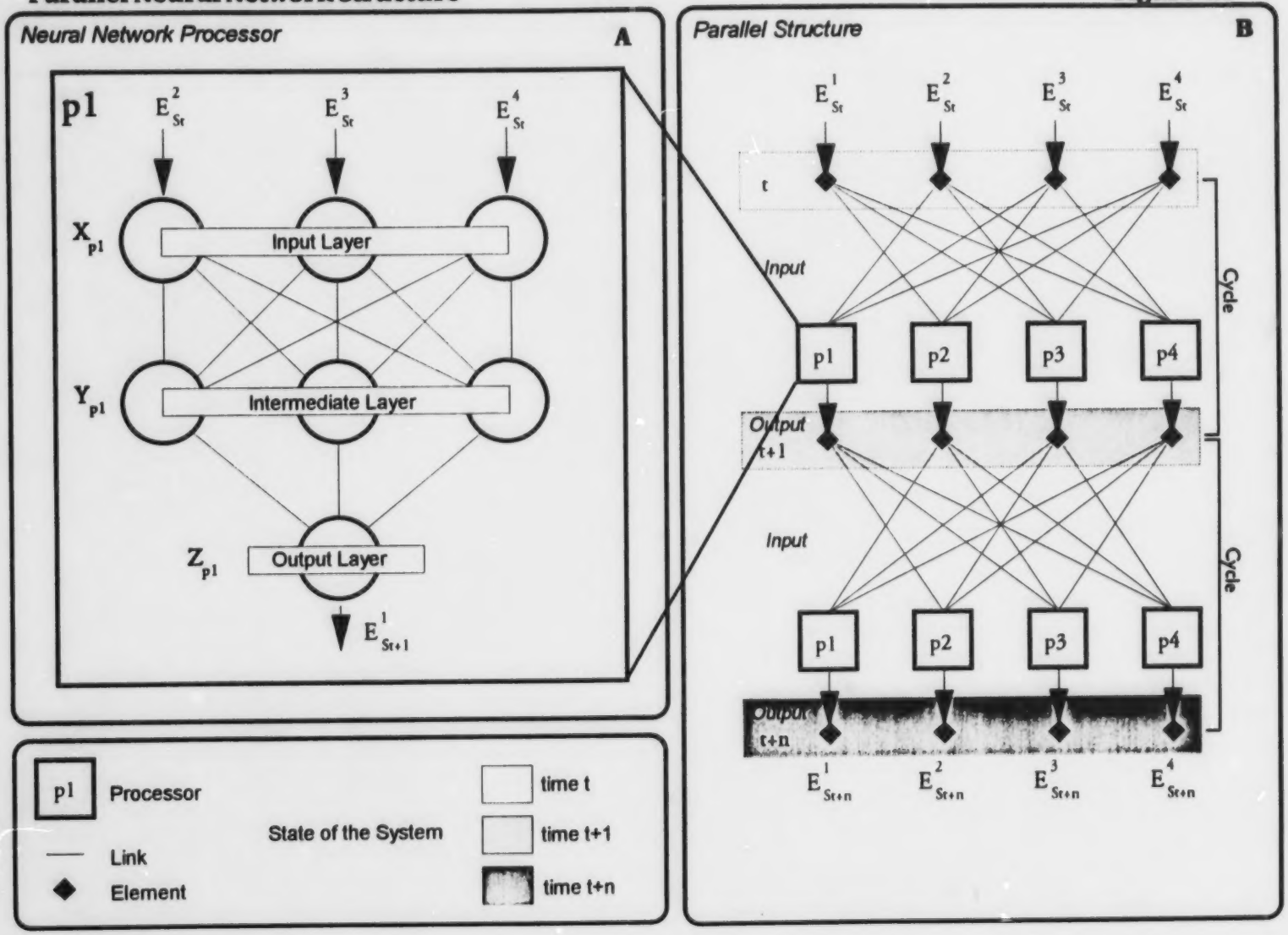


Table 5.1: Characteristics of a Fictive City

	Accessibility	Interactions	Employment	Population
Zone 1	9	10000	8000	1000
Zone 2	5	5000	2000	3000
Zone 3	4	6000	3000	4000
Zone 4	5	2000	1000	7000
Zone 5	2	1000	500	9000
Zone 6	7	3000	1000	6000
Zone 7	6	4000	2000	5000
Zone 8	4	2000	1000	8000
Zone 9	7	7000	4000	3000
Zone 10	2	1000	500	7000
Total	51	41000	23000	53000

Four neural network processors were configured (see section 4.2): The interaction processor (*p4*), the accessibility processor (*p3*), the population processor (*p3*) and the employment processor (*p4*) (see figure 2.1).

Table 5.2: Effects of Elements Over Interactions (Interaction Processor)

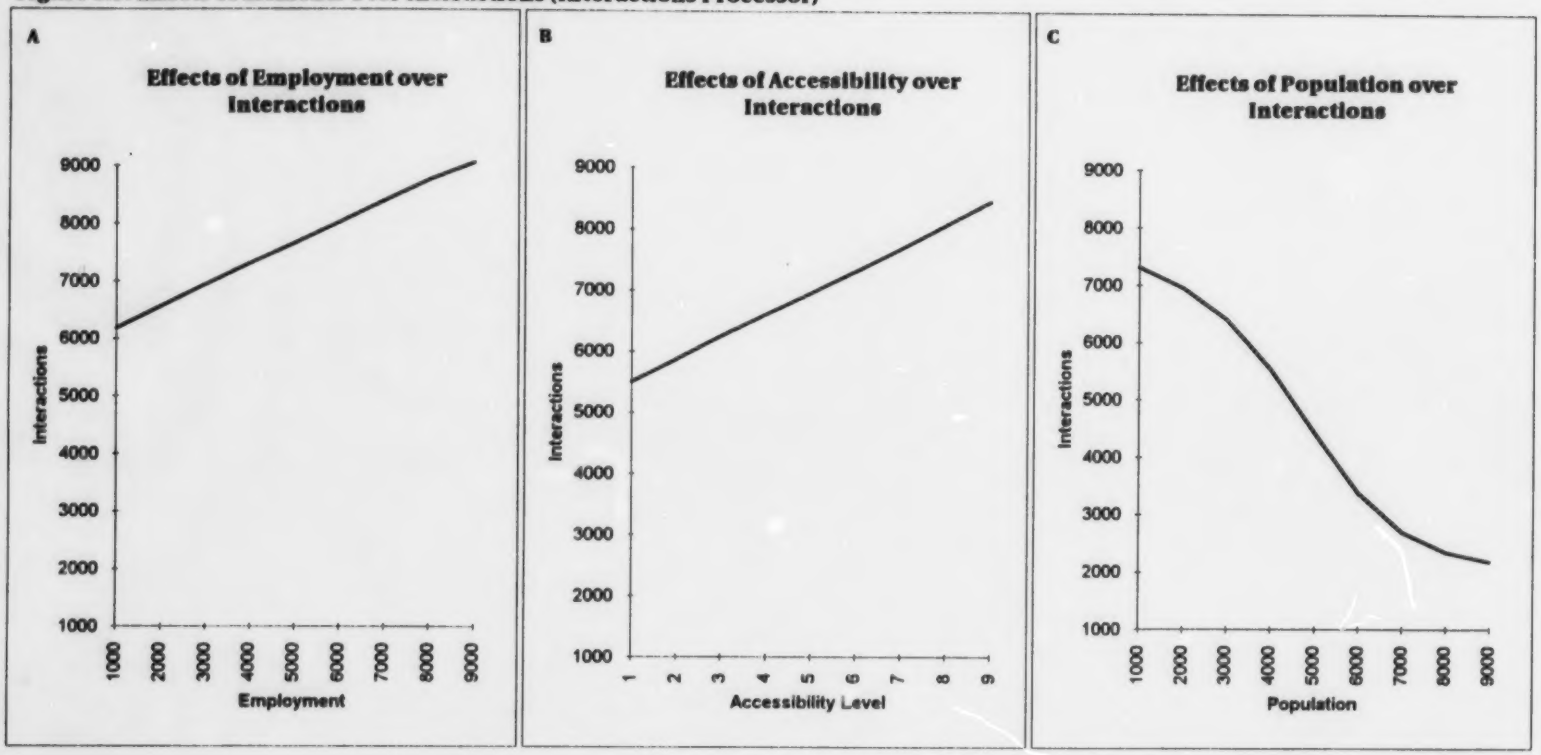
Accessibility	Interactions	Employment	Interactions	Population	Interactions
1.0	5500	1000	6179	1000	7309
2.0	5869	2000	6571	2000	6955
3.0	6241	3000	6955	3000	6391
4.0	6606	4000	7317	4000	5538
5.0	6955	5000	7671	5000	4424
6.0	7304	6000	8034	6000	3384
7.0	7671	7000	8405	7000	2703
8.0	8058	8000	8761	8000	2347
9.0	8445	9000	9062	9000	2174

Table 5.2 and Figure 5.1 illustrate that a neural network processor can represent at the same time linear (A and B) and non-linear (C) relationships. Those values were obtained by varying one element at a time and keeping the others constant. The neural network processors are able to capture the patterns of relationships between the elements of the transportation / land use system of the fictive city. If an element change, the neural network processors calculate the impacts on others assuming that the patterns of relationships remain the same.

6. Discussion

The first point worth underlining is that the developed model is not an optimization of transportation and land use, but rather a parallel simulation procedure of the urban structure that can be used as a planning tool. This procedure is highly flexible because it does not have goals except than to simulate the probable impacts of given changes on its elements. Most models are looking for an optimal level to raise the transportation / land use system functional level. But, is it necessary to look for an optimal level to attain a functional one? This question remains pertinent as each city is a

Figure 5.1: Effects of Elements Over Interactions (Interactions Processor)



complex transportation / land use system with multiple constraints and where an optimal level often cannot be conceived by planners. An optimal city is strictly a theoretical city (Los, 1979). Indeed, a functional transportation / land use system is a system where transportation problems are causing few losses of comparative advantages for land use zones. This is a fundamental part of the problematic of city planning. Cities offer the planner a set of possible alternatives, but no single optimal. No city can afford all the structural transformations required for an optimal state. An optimal state can broadly be conceived by no congestion, an equitable distribution of economic activities and of spatial accumulation, and by a structured pattern of movements of all modes. These points underline the idea that optimization is not necessary to attain a functional state. The developed model methodology takes that concept into account because optimization is not an endogenous goal of the model.

From an operational point of view there is an exponential growth of the complexity of the parallel structure as the number of element increase. The granularity increases as the number of processors do. However this is not really a constraint with the computational power of actual systems, even personal computers. We have advanced that parallel and sequential models follow the same logic, so why use a parallel structure? A parallel structure is much faster than a sequential structure, but more important parallel distributed processing offers a new conceptual framework in transportation / land use modelling. Elements affecting each other concomitantly instead of sequencially is more realistic but much more difficult the conceptualize because there is no specific order in the relationships. For instance, a sequential model could consider that elements *A*, *B*, *C* and *D* influence each other in that particular way: $A \rightarrow B \rightarrow C \rightarrow D$. In a parallel model every elements could influence each other in any order. Of course some relationships are conceptually impossible and the planner must limit himself with a set of possible relationships (see tables 2.1 and 2.2 for instance). This problem can be overcome with neural networks that find the relationships and their strength between a set of elements.

The developed parallel model have several drawbacks. First, it requires some "initial momentum", that is changes in at least one of its elements, to be able to function. Second, a neural network processor is quite convenient but have several limitations. Basically a neural network is a pattern associator, it captures the current structure of relationships between elements, but as the nature of relationships changes (with new economic conditions for instance), the neural network model is likely to be far less accurate. However, this weakness is to be shared with almost all existing models. If a neural network is trained with a too small error margin, it will simply replicate perfectly the relationships with very few potential for generalization. Experiments in the field of neural networks have demonstrate that an error margin from 5 to 10% enable the network to have a good potential for generalization without losing too much accuracy (see Anderson and Rosenfeld, 1988). The induction capacitities of the neural network are limited by the availability and accuracy of data. Instead of starting from a set of equations and comparing their results with the real ones for calibration, a neural network directly capture the relationships between the elements. Without that induction procedure, a neural network have no deduction potential. For instance, a spatial interaction equation is purely deductive. With data such as the population of spatial entity, a spatial interaction equation predicts the flows between spatial entities. In order to do the same thing, a neural network can be used in two ways. First, with the observed flows, a neural network can model the spatial interactions of a system. This is the most desirable alternative. Second, when the observed flows between spatial entities are not available, a neural network can be used to copy the results of a spatial interaction model. In that case, a neural network is no better than the spatial interaction model it replicate.

7. Conclusion

A transportation / land use system is a complex spatial system composed of several elements representing the level of spatial accumulation. Elements are variables used to express the state of a system at a given point in time. Therefore the state of variables like interaction, accessibility, economic structure and population is the functional land use. We have suggested that sequencial urban modelling does not well represents complex urban dynamics. Instead, we have proposed a parallel distributed processing structure composed of processors and links between processors with a specific parallel internal structure. Each processor is a set of neurons and weights between neurons forming a neural network.

Parallel distributed processing offers new methodologies to represent the relational structure between elements of a transportation / land use system and thus the modelling of those systems. Future directions of research involve experiments with several types of parallel structures. In this paper we have showed only one parallel structure, several other are possible. Other types of neural networks also exists (see Korn, 1991). Recent progresses in artificial intelligence

offer new perspectives for modelling like heuristics, expert systems and reasoning under uncertainty (see Partridge and Wilks, 1990). Above all, it is worth rethinking the concepts and methodologies behind modelling, so that this approach could be at least considered (instead of being discarded most of the time) in the proccess of transportation / land use planning.

Bibliography

Anderson, J.A. and Edward Rosenfeld (eds) (1988) Neurocomputing: Foundations of Research, The MIT Press, Cambridge, Massachusetts.

Berechman, J. and K.A. Small (1988) "Research policy and review 25. Modeling land use and transportation: an interpretive review for growth areas", Environment and Planning A, Vol. 20, pp. 1285-1309.

Caudill, M. (1990) Neural Network Primer, AI Expert, Miller Freeman Publications, San Francisco.

Korn, G.A. (1991) Neural Network Experiments on Personal Computers and Workstations, The MIT Press, Cambridge, Massachusetts.

Los, M. (1979) "A discrete-convex programming approach to the simultaneous optimization of land use and transportation", Transportation Research B, Vol. 13, No. 1, pp. 33-48.

Lowry, L.S. (1964) A Model of Metropolis, The Rand Corporation, Santa-Monica.

Macmillan, B. (1989) Remodeling Geography, Basil Blackwell, Cambridge, England.

Negoita, C.V. and D. Ralescu (1987) Simulation, Knowledge-Based Computing, and Fuzzy Statistics, Van Nostrand Reinhold Company, New York.

Nolen, T. (1992) "Parallel processing for problem solving", AI Expert, Vol. 7, No. 2, pp.34-40.

Openshaw, S. (1986) "Modelling relevance", Environment and Planning A, Vol. 18, pp. 143-147.

Partridge, D. and Y. Wilks (eds) (1990) The Foundations of Artificial Intelligence. A Sourcebook, Cambridge University Press, Cambridge.

Pryor, E.G. (1987) "Land use - transport strategy formulation in Hong Kong", Land Use Policy, July, pp. 257-279.

Pumain, D., Th. Saint-Julien and L. Sanders (1987) "Application of a dynamic urban model", Geographical Analysis, Vol. 19, No. 2. pp. 152-166.

Scott, A.J. and N. Storper (eds) (1986) Production, Work, Territory: The Geographical Anatomy of Industrial Capitalism, Boston: Allen & Unwin.

Sejnowski, T.J. and C.R. Rosenberg (1988) "NETtalk: a parallel network that learns to read aloud", in Anderson, J.A. and E. Rosenfeld (eds) Neurocomputing: Foundations of Research, The MIT Press, Cambridge, Massachusetts, pp. 663-672.

Webster, F.V., P.H. Bly and N.J. Paulley (eds) (1988) Urban Land-use and Transport Interaction: Policies and Models: Report of the International Study Group on Land-use/Transport Interaction (ISGLUTI), Gower Publishing Company Limited, Aldershot.

White, R.W. (1989) "The artificial intelligence of urban dynamics: Neural network modeling of urban structure", Papers

of the Regional Science Association, Vol. 67, pp. 43-53.

Zadeth, L. (1965) "Fuzzy sets", Information and Control, Vol. 8, pp. 338-355.